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TENSILE PROPERTIES OF ARECA LEAF SHEATH (ALS) SUBJECTED TO FLATTENING PROCESS FOR DISPOSABLE PLATE MAKING APPLICATION: EFFECT OF THICKNESS AND FLATTENING PRESSURE

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ABSTRACT

Areca Leaf Sheath (ALS) is a common agricultural waste produced in Southeast Asia countries, which is widely utilized over the decades to make biodegradable disposable dining wares. The workable surface of ALS for heat pressing is limited due to the concavity in the middle and folding at the edges of ALS. This study proposes that the ALS is flattened using a padding mangle prior to the forming process. The aim is to investigate the effect of ALS thickness and flattening pressure on the ultimate tensile strength and percentage strain at break of ALS. The data obtained is subjected to ANOVA statistical analysis. The morphology of ALS is analyzed under a fluorescent microscope and its chemical composition is also identified. It is found that ALS thickness and flattening pressure affect the results differently. The highest ultimate tensile strength (mean of approx. 32 MPa) is obtained from grain direction samples flattened at 5 bar, regardless of their thicknesses; whereas the highest strain is mean of 41.58% from perpendicular grain direction samples flattened at 5 bar, with thickness of <2.5 mm. The results can help to reduce waste from raw material in the production ALS disposable dining wares.

KEYWORDS: Areca Leaf Sheath, Tensile Properties, Flattening, Morphology, Disposable & Dining Ware

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Original Article

INTRODUCTION

There has been growing public awareness for environmentally friendly and sustainable products in recent years to preserve our Mother Earth (Pickett Baker & Ozaki, 2008). However, in recent Malaysia's context, the usage of plastic disposable dining wares is still widespread in various restaurants. According to a study done by Jambecket al. (2015), Malaysia is in the eighth position among the countries that have created the worst plastic wastes among 192 countries. This problem urges effective alternatives to replace plastics as the raw material to produce disposable dining wares since the usage of disposable products are understandably unavoidable in the daily lives of urban citizens. There are countless attempts done by researchers and companies to produce paper and bio-based polymers products (Jirukkakul, 2019). A simple yet sustainable raw material has been used traditionally for decades in India to make disposable dining wares such as plates, cups and bowls, which is the Areca Leaf Sheath (ALS).

The Areca palm tree is usually referring to the most cultivated species *Areca Catechu* Linn. The plantation of Areca palm trees is motivated by the recreational chewing habit of its nut in South Asia and the Pacific Oceanic regions (Mateen et al., 2017). ALS is the extension of the rachis of the Areca leaf, which completely encircles the tree stem of Areca palm. The ALS sheds 5-6 times a year per tree (Bavappa et al., 1982). An adult ALS is concaved in the center, it also has a greenish or brown, waxy and tough outer surface, with a glossy creamy-colored inner surface (Bavappa et al., 1982). ALS is an agricultural waste at the Areca palm plantation fields. Usually, the fallen ALS are collected and then burnt off due to its slow decomposition rate. Open burning contributes to global warming and carbon deposit. Thus, the locals impart commercial values to this biodegradable resource by utilizing it to be the raw material for producing disposable plates and containers (Nikhil et al., 2018; Kalita et al., 2008).

The ALS disposable plates have a simple and energy efficient manufacturing process. The raw ALS are collected from the Areca palm plantation once the sheaths fall from the trees. After that, the sheaths need to be sun dried and stored. Normally, the drying and storage time is around six months. To shorten the time of drying ALS, there was an attempt to develop a cost-effective solar dryer (Nikhil et al., 2018). Then, the sheaths are being washed manually in water by using a brush. ALS absorbed water during this process, thus gaining some moisture, making it more flexible for pressing afterwards. Then, the dried sheaths were placed into the pressing machine, with the pressing dies heated up to certain temperatures by external energy source. The ALS were pressed for a while to conform its structure to the shape of the mold. It should be noted that the moisture content of the sheaths should be maintained at above 5% to prevent cracks on the material. If the moisture content of the pressed plates is too high, then the plates need to be used immediately to prevent fungi from growing; or else it needs to be dried. The dried ALS product can be stored for up to 12 months. Finally, the manufactured products are packaged in bundles in plastic bags to keep them dry and hygienic before used(Nikhil et al., 2018;Clein & Tang, 2016).

There is no study found regarding the microstructure study of ALS except its physical properties (Shashikumar et al., 2016). Lignocellulosic materials like ALS are made up of natural polymers like cellulose, hemicellulose, lignin and some other minor components. A few researches reported these chemical compositions of ALS (Padmaraj et al., 2013; Nagaraja et al., 2014; Poddar et al., 2016; Banagar et al., 2018). However, limited study has been done about processing ALS to be disposable dining wares, like a research carried out by Kalita et al.(2006), which the factors of moisture content of ALS and temperature during production are studied. On top of the fact that ALS dining ware production is sustainable and energy-efficient, there is limitation on the workable surface of the mature ALS caused by its concavity in the center and the folds on the sheaths (Bavappa et al., 1982). These characteristics of ALS result in material waste as the manufacturers get rid of the folded parts of ALS after pressing only the flat surface. As far as the authors are aware, there is no literature found to cater this limitation. This study embarked on the aim to solve this problem by proposing the ALS to be flattened before it is pressed into the shapes of containers. The tensile properties of the ALS before and after the flattening process are investigated. Factors that were considered to affect the tensile properties are the thickness of ALS and the flattening pressure of the padding mangle used. The effect of these factors are analyzed using analysis of variance (ANOVA) techniques in the current study.

METHODS

Material

In this study, samples of ALS originated from Indonesia were used. The samples were stored in an air conditioned laboratory (65% RH, 23˚C) after collected. Prior to the experiment, the surface of the samples was cleaned thoroughly with

a wet cloth to remove the particles accumulated. The ALS has non-uniform thicknesses over the surface. The maximum and minimum thicknesses measured from the ALS using a Vernier caliper (0.05 mm accuracy) are 8.2 mm and 0.9 mm respectively. The maximum thickness used in this study is 4.5 mm for the ease of manual cutting, despite the huge difference between thicknesses.

Morphology Study on ALS Fiber

The morphology of ALS fiber is studied by carrying out the maceration process according to Technical Association of Pulp and Paper Industry (TAPPI) Standard T233-Su-64 and a study by Nor Mazlana et al.(2014). The fibers were cut into matchstick of 25 to 30 mm in length and 2 mm in width. Then, 25 ml distilled water was added with 1.5 g sodium chlorite into test tubes that contain the fibers. After the test tubes were being water bathed for 24 hours, the fibers were shaken in distilled water to obtain the individual fibers. To give color pigment to the fibers, a drop of safranine-O was dropped into the fibers for color pigmentation and the fibers were left for 1 hour. Then, some individual fibers from different test tubes were transferred into a slide. From the slide, 50 fibers were measured under a Quantimeter Image Analyzer equipped with Leica fluorescence microscope (Leitz DMRB, German) to obtain the average fiber length, fiber diameter, lumen diameter and fiber cell-wall thickness.

Chemical Analysis

The ALS were cleaned and then cut into small pieces to be ground into fine fibers using a Thomas Wiley Mill (Model 4, United States). The ground fibers were then sieved through BS 40-mesh (425 µm) and BS 60-mesh (250 µm) to obtain finer fibers, in accordance to Technical Association of the Pulp and Paper Industry (TAPPI) Standards T 257 cm-02 - Sampling and Preparing Wood for Analysis. Holocellulose content of ALS was determined according to Wise *et al.* (1946). α- cellulose content, was analysed according to the procedure described in the TAPPI T 203 os-74. Next, pentosan content was identified using the method of Savard et al.(1954). Whereas, the chemical contents of α-cellulose, lignin, alkali solubility, water solubility, ash and silica content were investigated according to TAPPI Standard Methods T 203 os-74, T 222 om-02, T 212 om-02, T 207 cm-99, and T 211 om-02, respectively. Three replications were done for each analysis. The content of hemicellulose can be obtained through the difference between the values of holocellulose and α- cellulose content of the fibers.

Flattening Process

Due to the concavity of ALS in the center, this study proposes that the sheaths be flattened using a vertical laboratory padding mangle (Model P-AO, China). The padding machine has a range of flattening pressure options from 1 bar to 5 bar. Three parameters of the flattening pressure were chosen, i.e. 0 bar (as control), 1 bar, and 5 bar. The 1 bar and 5 bar of pressure were chosen to investigate the minimum and maximum effect of the pressure on ALS. ALS was fed into the rollers in the directions that are parallel and perpendicular to the grains for parallel and perpendicular oriented tensile test samples respectively. The flattening process was repeated for three (3) times each sample.

Experimental Design

A completely randomized 2 to 3 factorial experimental design was employed to investigate the effect of ALS thickness and flattening pressure on the tensile properties of ALS, i.e. ultimate tensile strength and strain percentage. ALS thickness has 2 levels of category (<2.5 mm, >2.5 mm), whereas the flattening pressure has 3 levels (0 bar, 1 bar, 5 bar). The samples with 0 bar flattening are basically the controls. The interaction between these two factors is also studied. As five (5)

replications were needed for each level, one experiment set requires a total of thirty (30) experimental runs. Since ALS is an anisotropic material, two sets of experiments were carried out for both parallel and normal directions to the grain of ALS.A randomized run order for one experiment set was generated using Minitab 18.1software to minimize the biasness in the experiments as shown in table 1below.

Table 1: Randomized Run Order Generated by Minitab 18.1

Standard Order	Run Order	Thickness, mm	Pressure, bar
14	1	<2.5	1
8	2	<2.5	1
20	3	<2.5	1
15	4	<2.5	5
13	5	<2.5	0
6	6	>2.5	5
1	7	<2.5	0
21	8	<2.5	5
2	9	<2.5	1
25	10	<2.5	0
16	11	>2.5	0
23	12	>2.5	1
28	13	>2.5	0
3	14	<2.5	5
12	15	>2.5	5
10	16	>2.5	0
4	17	>2.5	0
9	18	<2.5	5
29	19	>2.5	1
27	20	<2.5	5
17	21	>2.5	1
26	22	<2.5	1
11	23	>2.5	1
22	24	>2.5	0
5	25	>2.5	1
18	26	>2.5	5
19	27	<2.5	0
7	28	<2.5	0
30	29	>2.5	5
24	30	>2.5	5

Tensile Test

Tensile test was conducted in accordance with ASTM D638-14, Standard Test Method for Tensile Properties of Plastics. The tests were conducted on Universal Testing Machine (Lloyd LR30K Plus, Canada). The ALS were cut manually into dumbbell shape, where in ASTM D638 is classified into the Type I specimen. The sample dimensions are as illustrated in figure 1.The samples that break outside of the narrow gage length section were discarded and new samples were taken for retests. The speed of testing was set at 5 mm/min as specified in the standard, for a rupture time within 5 min. The width and thickness of the ALS tensile test samples were measured with a Vernier caliper to the precision of 0.05 mm. the precision level is sufficient since the application of ALS does not require tight tolerance of its dimensions.

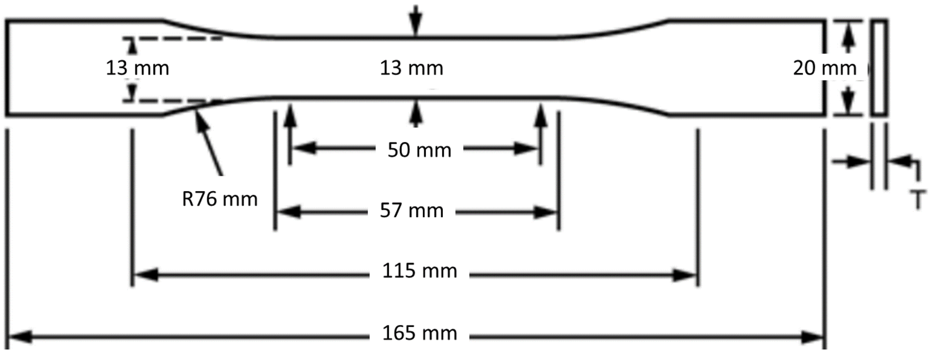

Figure 1: Dimensions of Tensile Test ALS Samples.

Statistical Analysis

The main effects and interaction of ALS thickness and pressure on response variables were analyzed by two-way ANOVA followed by Tukey Pairwise Comparison Test using Minitab 18.1 software. The response variables are ultimate tensile strength and strain percentage. The factors with low probability value ($P \leq 0.05$) were identified to have significant effect on the responses of tensile test in this study.

RESULTS

Morphology Study on ALS Fiber

As shown in figure 2, the lumen and cell wall of a pigmented ALS fiber can be clearly observed and measured under the fluorescence microscope. Table 2below compares a few stiff fiber types that have similar values of fiber dimensions to ALS fiber. The tensile strength and strain of the fibers are also shown. In brief, the means for the fiber length, fiber diameter, cell wall thickness and lumen diameter of ALS fibers are 1.77 mm, 22.00 µm, 4.20 µm and 13.60 µm respectively. According to Komuraiah et al. (2014) and Zhang et al.(2015), plant fibers need to have long fiber length, small diameter, small lumen diameter and thick cell-wall to have higher tensile strength. From the results obtained in table *2*, it can be deduced that ALS fiber should have higher tensile strength than coir and bagasse fibers, but lower than kenaf and sisal fibers.

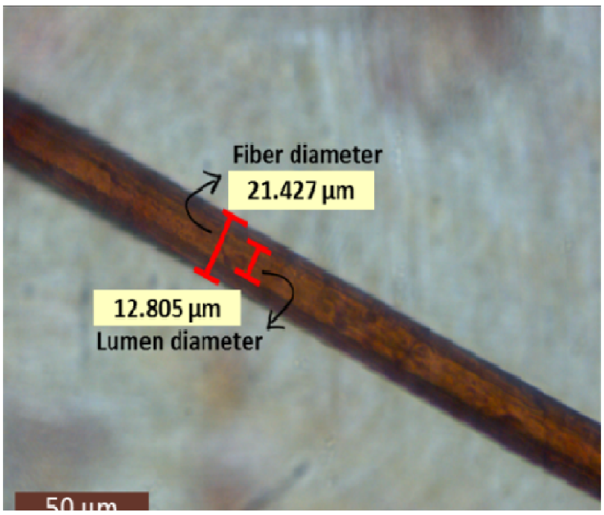

Figure 2: Measurement of Fiber Diameter and Lumen Diameter on One of the ALS Fibers

Table 2: Comparison of ALS Fiber Dimensions with Some Other Plant Fibers.

Fiber type	Length (mm)	Diameter (µm)	Cell-wall thickness (µm)	Lumen diameter (µm)	Tensile strength, MPa	Strain, %	Reference
ALS	*1.77 ± 0.63*	*22.00 ± 4.60*	*4.20 ± 0.70*	*13.60*	-	-	*Current study*
Coir	0.84 ± 0.17	20.09 ± 3.84	4.41 ± 1.14	13.59 ±3.26	106.00 – 175.00	15.00 – 40.00	(Mwaikambo, 2006), (Komuraiah et al., 2014), (Nor Mazlana et al., 2014)
	0.90 – 1.20	16.20 – 19.50					
	1.25	17.5					
Sisal	1.80 – 3.10	18.30 – 23.70	-	-	80.00 – 840.00	2.00 – 14.00	(Ansell et al., 2009), (Komuraiah et al., 2014)
	2.50	21.00				8.00	
Kenaf (bark)	2.32 ± 0.21	21.9 ± 4.60	4.2 ± 0.8	11.90 ± 3.40	295.00 – 1191.00	-	(Ververis et al., 2004), (Komuraiah et al., 2014)
	2.35	19.80			743		
Bagasse	1.70	20.00	-	-	290.00	-	(Tewari et al., 2012), (Komuraiah et al., 2014),
	0.61	13.00					

Chemical Analysis

Table 3below shows the comparison of ALS chemical composition results obtained by current study to a few other studies. The results obtained are generally in agreement with values reported by Banagar et al. (2018) and Padmaraj et al. (2013). The difference of results may be caused by the difference in analysis methods used and different geographical and climate conditions of the plant origin (Komuraiah et al., 2014).It is to be noted that ALS fiber generally has lower cellulose content than other commercialized non-wood plant fibers such as hemp, flax, cotton, jute, sisal and ramie fibers. A generally lower cellulose content of ALS indicates that it is expected to have lower tensile strength compared to these fibers. From table 3,the chemical composition of ALS is similar to that of bagasse, bamboo, piassava and kenaf fibers (Komuraiah et al., 2014). A higher value of hemicellulose and lignin of ALS increases the rigidity and hydrophobicity of the material. This aids in its ultimate function to contain wet foods without losing its dimension stability(Liu et al., 2018).

Table 3: Chemical Composition of ALS Fiber.

Chemical composition	Content (%)				
	Current study	(Banagar et al., 2018)	(Padmaraj et al., 2013)	(Nagaraja et al., 2014)	(Poddar et al., 2016)
α – cellulose	30.30	34.82	-	26.40	66.08
Hemicellulose	40.20	25.68	35.00 – 64.80	16.00 – 17.00	7.40
Lignin	14.40	16.58	13.00 – 24.00	38.68	19.59
Ash	5.40	10.86	4.40	-	-
Alkali solubility	37.60	-	-	-	-
Pentosan	13.90	-	-	-	-
Ethanol-toluene	4.40	-	-	-	-
Moisture	16.32	12.06	8.00 – 25.00	-	-

Effect on Ultimate Tensile Strength and Strain of ALS

Table 4presents the ultimate tensile strength and strain obtained at different combinations of ALS thicknesses and flattening pressures for both parallel and perpendicular directions to the grain lines.

Table 4: Ultimate Tensile Strength and Strain Percentage for Parallel and Perpendicular Oriented Samples.

Pressure, bar	Thickness, mm	Parallel Oriented		Perpendicular Oriented	
		Ultimate Tensile Strength, MPa	Strain, %	Ultimate Tensile Strength, MPa	Strain, %
5	>2.5	31.596	7.209	0.952	32.712
5	<2.5	31.858	8.271	1.057	41.576
1	>2.5	29.184	5.747	0.985	21.223
1	<2.5	25.732	7.882	0.976	18.145
0	>2.5	25.360	7.459	1.247	8.109
0	<2.5	22.196	7.304	1.134	20.622

It can be clearly seen from Table 4, the tensile strength of the ASL samples at parallel direction is over 20 times higher than those at the perpendicular direction. The even fracture surface of perpendicular oriented samples shows that it is brittle, while the parallel samples that shows irregular splitting along the longitudinal direction indicates that it has high toughness(Figure 5). The irregular splitting of parallel oriented tensile test sample also is observed on the bamboo block tensile test sample(Shao et al., 2010).It is also observed that the stress-strain curve is smooth for parallel sample while otherwise is observed for perpendicular sample in figure 6. As the tensile force was applied on the parallel sample, the longitudinal bundled fibers elongated and broke abruptly at the breaking point together. While the irregular pattern of the perpendicular stress-strain graph is caused by the gradualside-by-side detachment of fibers during tensile testing.

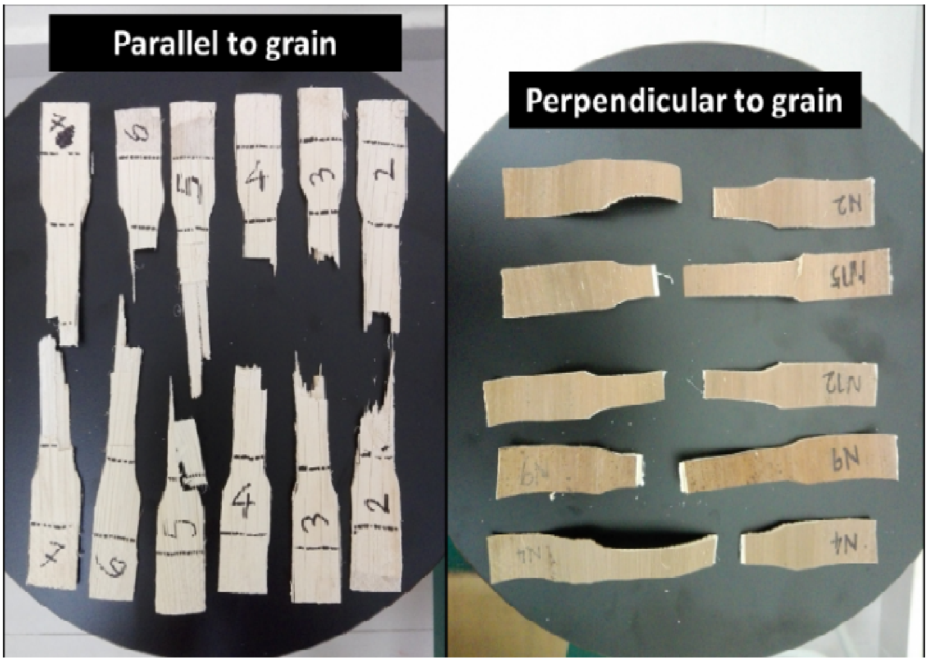

Figure 3: Breaking Pattern of Tensile Test Samples.

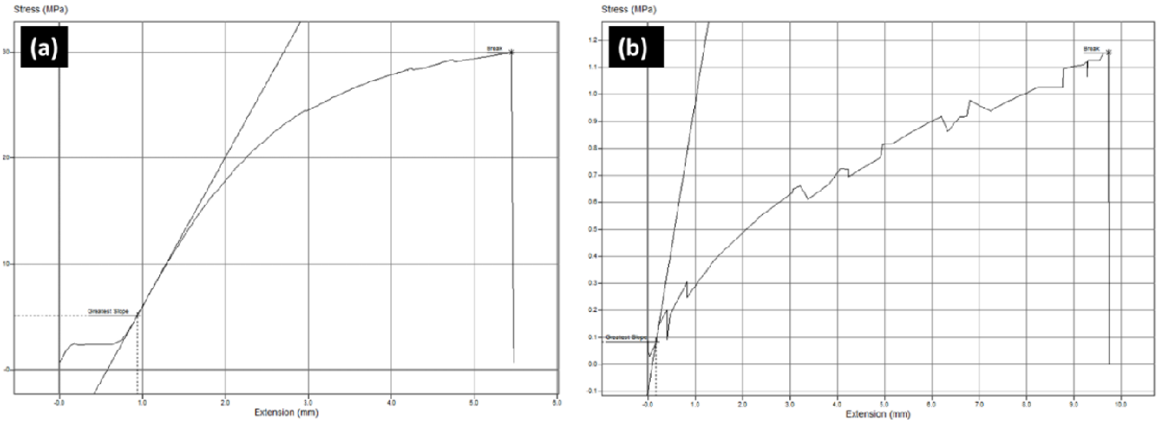

Figure 4: Stress-Strain Graph for (a) Parallel (b) Perpendicular Oriented Samples.

From table 5, the ultimate tensile strength of the parallel oriented samples were significantly influenced by the flattening pressure (P=0.01). As the pressure increases, the tensile strength also increases for both categories of thicknesses (refer to Table 4). This is due to larger pressure compacted the ALS without breaking them to create a smaller cross-sectional area.A compact material with smaller cross-sectional area exhibits higher tensile strength than loose material (Witt & Zeh, 2007). Table 7below shows the grouping information by Tukey comparison test for effect of pressure on ultimate tensile strength in parallel oriented category. It is found that the samples that went through 5 bar pressure is significantly different from the control. Whereas, samples that were flattened at 1 bar do not show significant difference from other two.

Table 5: Two-Way ANOVA Result for the Effect on Ultimate Tensile Strength

Source	Parallel				Perpendicular			
	Adj SS	Adj MS	F-Value	P-Value	Adj SS	Adj MS	F-Value	P-Value
Thickness	33.64	33.64	1.20	0.284	0.00021	0.000209	0	0.965
Pressure	316.51	158.26	5.65	0.010	0.25735	0.128676	1.21	0.318
Thickness*Pressure	21.35	10.67	0.38	0.687	0.05937	0.029684	0.28	0.76
Error	671.85	27.99			2.45492	0.106735		
Total	**1043.35**				**2.77186**			

Table 6: Two-Way ANOVA Results for the Effect on Strain Percentage

Source	Parallel				Perpendicular			
	Adj SS	Adj MS	F-Value	P-Value	Adj SS	Adj MS	F-Value	P-Value
Thickness	7.119	7.119	2.46	0.131	279.1	279.1	1.68	0.207
Pressure	3.881	1.94	0.67	0.521	2840.1	1420.1	8.56	0.002
Thickness*Pressure	6.2	3.1	1.07	0.359	332.5	166.3	1	0.382
Error	63.584	2.89			3979.7	165.8		
Total	**80.894**				**7431.4**			

Table 7: Grouping Information by Tukey Method for Effect of Pressure for Parallel Oriented Samples on Ultimate Tensile Strength

Pressure, bar	Mean	Grouping
5	31.727	A
1	27.458	AB
0	23.778	B

However, the above phenomenon mentioned does not apply to the perpendicular oriented samples(Table 5). There is no significance difference neither by thickness nor pressure on ultimate tensile strength of perpendicular oriented ALS. It is also interesting to note that the application of pressure on the perpendicular samples actually lowered their tensile strength especially for the thicker samples as observed from table 4. This is due to cracking during the flattening process as illustrated in figure 7.Thus, it is concluded that flattening the ALS along the parallel grain orientation at 5 bar pressure helps to increase the tensile strength of the material. By this, another objective of increasing the workable surface of ALS for hot pressing is also simultaneously achieved.

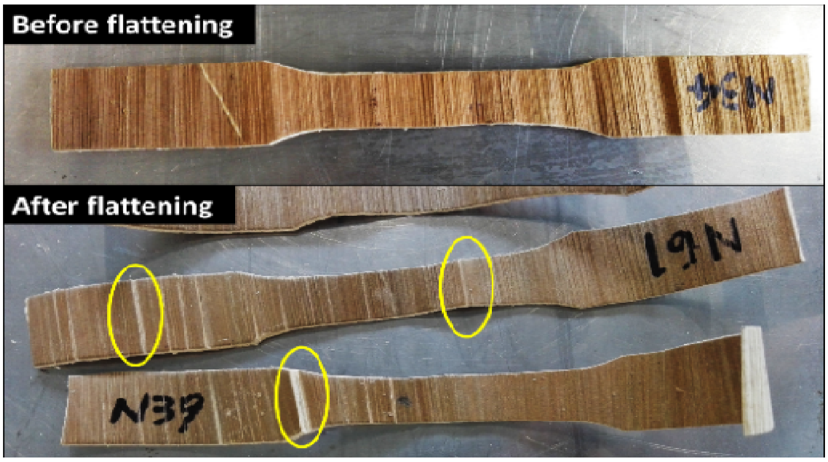

Figure 5: Cracking Happened on the Perpendicular Oriented Samples During Flattening Process, the Circled Parts Indicate the Cracks.

The ultimate tensile strength obtained for parallel and perpendicular oriented samples before being flattened regardless of their thickness are 23.78 MPa and 1.19 MPa respectively. The results are compared to other studies in Table8. The result of parallel grain samples is consistent with the value reported by Banagar et al.(Banagar et al., 2018). The huge difference of tensile strength value with other two studies may be caused by the different methods used.

Table 8: Comparison of ALS Tensile Strength Between Different Studies.

Sl. No.	Tensile strength, MPa		Method used	Reference
	Parallel	Perpendicular		
1	136.36–163.63	0.18	Not specified	(P. Kalita et al., 2008)
2	140.00–160.00	0.15–0.20	Not specified	(Nikhil et al., 2018)
3	16.45	-	ASTM D3039	(Banagar et al., 2018)
4	23.78	1.19	ASTM D638-14	Current study

Strain or elongation is the ratio of the change in length to the original length of the tensile test samples. When a material has high strain, it does not fracture easily under the application of external tension force. When ALS is deformed during pressing which then exceeding its elastic limit, a high strain will prevent it from cracking easily. From the data collected in Table 4, the strain of perpendicular oriented ALS is generally higher than the parallel ones.

Both ALS thickness and pressure do not affect strain significantly for parallel oriented samples(Table 6). Whereas, the flattening pressure was significantly affecting the strain (P=0.002)for perpendicular direction samples. As the flattening pressure increases, the strain of perpendicular oriented samples also increases. Table 9 displays that non-flattened samples produce significantly different strain compared to the samples that were flattened.

Table 9: Grouping Information by Tukey Method for Effect of Pressure for Parallel Oriented Samples on Strain

Pressure, bar	Mean	Grouping
0	37.144	A
1	19.684	B
5	14.365	B

CONCLUSIONS

Present work proposes to flatten the ALS to increase the workable flat surface area for production of disposable dining wares. The ALS fiber-dimensions were examined and the average values are 1.77 mm, 22.00 µm, 4.20 µm and 13.60 µm respectively for their fiber length, fiber diameter, cell-wall thickness and lumen diameter. The chemical composition for ALS is also identified. The contents for α-cellulose, hemicellulose, lignin, ash, alkali solubility, pentosan, ethanol-toluene and moisture are 30.30%, 40.20%, 14.40%, 5.40%, 37.60% 13.90% 4.40% and 16.32% respectively.

The effect of ALS thickness and flattening pressure on tensile properties of ALS is investigated. It is found that pressure has significant effect on ultimate tensile strength of parallel oriented ALS. Parallel directions specimens that were pressed at 5 bar irrespective of their thicknesses (<2.5 mm or >2.5 mm) are the strongest ultimate tensile strength quality. This has proven that flattening process helps not only to flatten the ALS surface and also in improving the cracking problem during heat pressing. Strain percentage is significantly affected by pressure only in perpendicular oriented sample category. As the pressure increases, strain of perpendicular samples also increases for both thickness categories from the lowest percentage 8.11% to the highest 41.58%. This information is useful for ALS disposable dining wares manufacturers as it will help to reduce the raw material waste.

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